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# HERMETIC COMPRESSOR MUFFLER DESIGN: TUNING OF MUFFLERS FOR NOISE REDUCTION

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## ABSTRACT

Designing a silent compressor, without many trials is possible when independent muffler results are available that give the muffler filtering frequency and transmission loss. Simple hand calculations can be done [1] and are generally used for a quick check. In this study, a discharge muffling system is studied and redesigned to widen the filtering frequency band for a low back pressure hermetic compressor generally used in domestic refrigerators.

First, the muffling system natural frequencies are found using Craggs' single dimensional finite element [2, 3]. Next, a four-pole, transfer matrix, formulation of Munjal [4] is used to obtain the transmission losses of the muffler. It is shown that electrical analogy helps in understanding the acoustic behaviour of muffling system. The muffler finally selected was used in making a prototype compressor and its noise spectrum is used in validating the design.

## INTRODUCTION

The mufflers in hermetic compressors are of reflective or reactive type in which acoustic energy is reflected back by area discontinuities and impedance mismatch. Table (1) shows the electroacoustic analogy as presented by Munjal [4].

TABLE (1) ELECTROACOUSTIC ANALOGY

S. No	ACOUSTIC TERM			CORRESPONDING ELECTRICAL TERM		
	VARIABLE	SYMBOL	UNITS	VARIABLE	SYMBOL	UNITS
01	Pressure	$p$	$N/m^2$	Voltage	$e$	Volts
02	Mass Velocity	$v$	$Kg / s$	Current	$i$	Amperes
03	Acoustical Impedance	$Z$	$1/ms$	Electrical Impedance	$Z$	Ohms
04	Resistance	$R (a_0/s)$	$1/ms$	Resistance	$R$	Ohms
05	Inertance	$M (l/s)$	$1/m$	Inductance	$L$	Henries
06	Compliance	$C (V/a_0^2)$	$ms^2$	Capacitance	$C$	Farads

This analogy helps in a better understanding of the functioning of a muffling system, which is now viewed as a series of acoustic elements.  $a_0$  is the velocity of sound in the refrigerant vapour,  $s$  is the sectional area of the acoustic element,  $l$  is the length of the

acoustic element in the direction of flow and  $V$  is the volume of the element.

Figures 1a and 1b show the discharge muffling systems under study and their equivalent circuits. Two steps of analysis are done in this design : (i) muffling system without a baffle plate, as shown in Figure 1a when the muffling is due to a simple expansion chamber, and, (ii) with a baffle plate, which is electrically equivalent to an in-line inertive impedance. In Figure 1a, element 1 is the downstream element, tail pipe or discharge pipe into the appliance to which the compressor is connected. Element 4 is the cylinder head plenum cavity, the upstream element.  $Z_0$  is the shunt compliance at the outlet and  $Z_s$  is the lumped in-line inertance. In Figure 1b, the design is modified to add a baffle plate, which is equivalent to an in-line inertance and the system will then have 6 elements as shown.

## ANALYSIS

**1.0 Finite element method (FEM):** A simple one-dimensional acoustic element [2, 3] as shown in Figure 2, for studying the acoustic properties of pipe system where transfer dimensions are small compared with the wave length, is used in this study. This element allows variation in pressure and area of tube. However, the boundary condition used is always  $p = 0$ , which corresponds to an open end tube. For a closed tube, when  $dp/dz = 0$ , using only a pressure boundary condition gives acceptable accuracy for lower natural frequencies. For the muffling systems shown in Figure 1, finite element analysis is performed to obtain the natural frequencies of the systems. One natural frequency is obtained for each degree of freedom, i.e., each unconstrained node of the finite element model.

## 2.0 Transfer matrix method (TFM)

**(a) Element transfer matrices:** Munjal [4] gives the Transfer Matrix Method (four-pole analysis) for each constituent element of a straight-through low-pass muffler. Acoustic pressure,  $p$  and mass velocity,  $v$  are state variables and for an  $r$ -th element, the element transfer matrix is as:

$$\begin{bmatrix} p_r \\ v_r \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix}_{r\text{-th element}} \begin{bmatrix} p_{r-1} \\ v_{r-1} \end{bmatrix} \quad \dots (1)$$

**(b) Transmission Loss:** The transfer matrix of the system is obtained by successive multiplication of element transfer matrices. Assuming anechoic termination, the transmission loss of the system (TL) is then calculated from system transfer matrix using:

$$TL = 20 \log [ (Y_1/Y_n)^{0.5} \cdot 0.5 \cdot | \{ T_{11} + T_{12}/Y_1 + T_{21} \cdot Y_n + T_{22} \cdot (Y_1/Y_n) \} | ] \quad \dots (2)$$

where,  $n = 5$  for the system in Figure 1a and  $n = 7$  for that in Figure 1b, and,  $Y_1$ ,  $Y_n$  are the end-characteristic impedances ( $a_0/S$ ) at the tail pipe and at the source respectively.

Two major assumptions which limit the accuracy of prediction of transmission loss are:

- (i) Plane wave assumption, which allows the 1-D representation of the muffling system. This assumption limits the accurate prediction of transmission loss only up to frequencies  $f < (1.84 \cdot a_0)/(\pi D)$ , which in this case for sound velocity  $a_0 = 587$  ft/s and maximum diameter  $D = 1.5$ " limits  $f$  to 2,745 Hz.
- (ii) Plane wave theory is applicable only for frequencies  $f < \{ (\pi \cdot a_0 \cdot (1 - M^2)^{1/2}) / (1.84 \cdot D) \}$  where  $M$  is the Mach number,  $D$  is the maximum diameter of

Figure 1a. Discharge muffling system without baffle plate

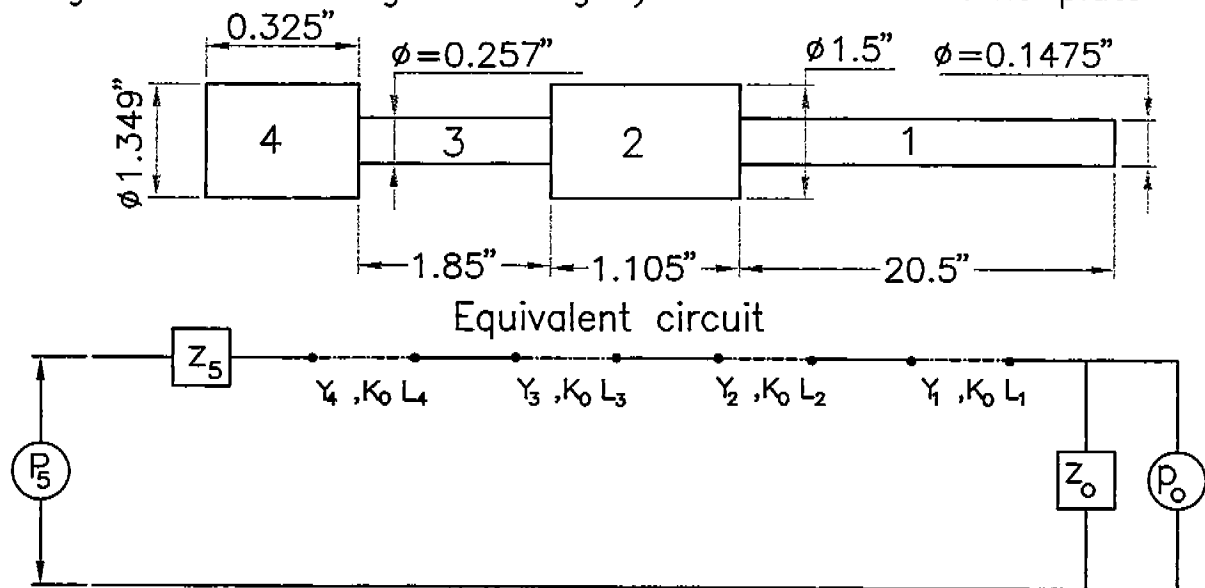


Figure 1b. Discharge muffling system with baffle plate

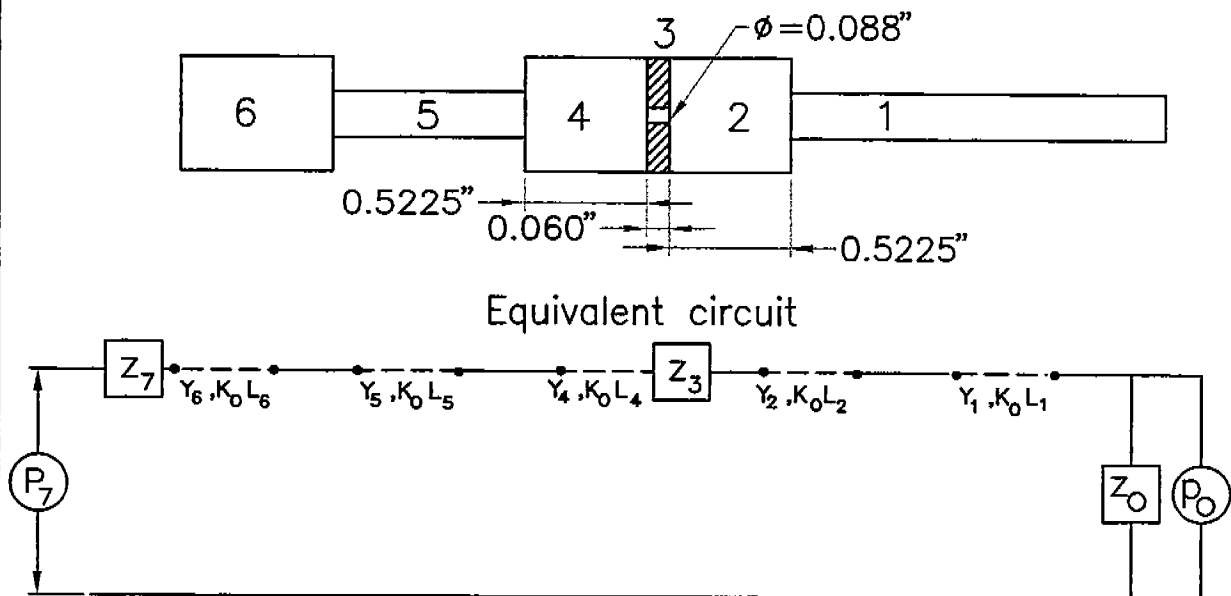
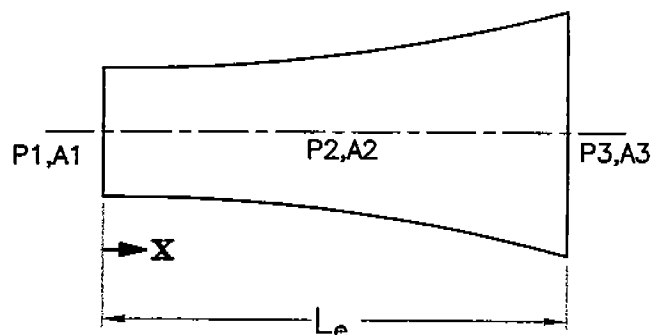


Figure 2. Variable section pipe element



the muffling system. It is shown that for typical automobile mufflers with circular tubes, Mach number is less than 0.2. In this case, Mach number  $M < 0.1$  and that limits the accurate prediction of frequencies up to 6,000 Hz.

Muffling system impedance ( $Z_s$ ): The impedance of the muffling system is obtained from the system transfer matrix by applying equation to the entire system, i.e.,

$$Z_s = (p_n - p_1) / (v_n - v_1) = (T_{11} \cdot Y_1 + T_{12} - Y_1) / (T_{21} \cdot Y_1 + T_{22} - 1) \quad \dots (3)$$

This leads to  $Z_s$  of the form  $A + iB$ , where  $A$  is the resistive part of the impedance and  $B$  is the combined inductive and compliant part. As in an R-L-C electric oscillator, the resonant frequency of the circuit is obtained when the imaginary part of the impedance tends to zero, i.e.,  $B = 0$ . For the case of the muffling system with and without baffle plate, the natural frequencies are calculated in this manner.

## RESULTS

From Figure 3, it is seen that introduction of a baffle plate has nearly doubled the transmission loss from 30 dB to 70 dB in the range of 600 to 5,400 Hz.

From Figure 4, it is noted that the finite element method (FEM) has given more natural frequencies as they depend on the number of degrees of freedom which is 29 in this case. From the muffling system impedance given by the TFM, the number of natural frequencies obtained depend on the number of muffling elements considered in the system which is 6 in this case. The natural frequencies match closely in both analyses, as shown in Table 2.

TABLE (2) Natural frequencies by TFM and FEM

Freq. No.	Natural frequency by FEM (Hz)	Corresponding natural frequency by TFM (Hz)
1	126.4	
2	179.2	200
3	345.3	350
4	510.1	
5	544.8	
6	704.6	
7	866.6	
8	1,139.5	
9	1,404.3	
10	1,706.4	
11	1,907.7	1,900
12	1,991.0	1,950
13	3,799.9	3,800
14	5,291.5	5,200
15	5,887.2	5,800

Figure 5 shows the comparison of transmission loss in discharge muffling system predicted by the transfer function method with the tested overall compressor sound pressure

levels. The discharge muffling is effective from about 600 to 5,400 Hz. The sources of noise peaks in the region of 50 Hz to 400 Hz have to be evaluated and if they occur in the discharge path, the discharge muffling range has to be extended to the lower frequencies. The source of compressor noise at 1230 Hz and 1600 Hz is most likely not in the discharge path since the transmission loss is high in this range.

## CONCLUSIONS

Finite element and Transfer matrix methods have been applied to obtain the natural frequencies and transmission loss for the discharge muffling system of a hermetic compressor. Electroacoustic analogy is established for this application. Computed values from the analysis were validated with experimental sound tests on a prototype compressor. This analytical method is general in nature and can be used for the study of any reflective type of muffling system.

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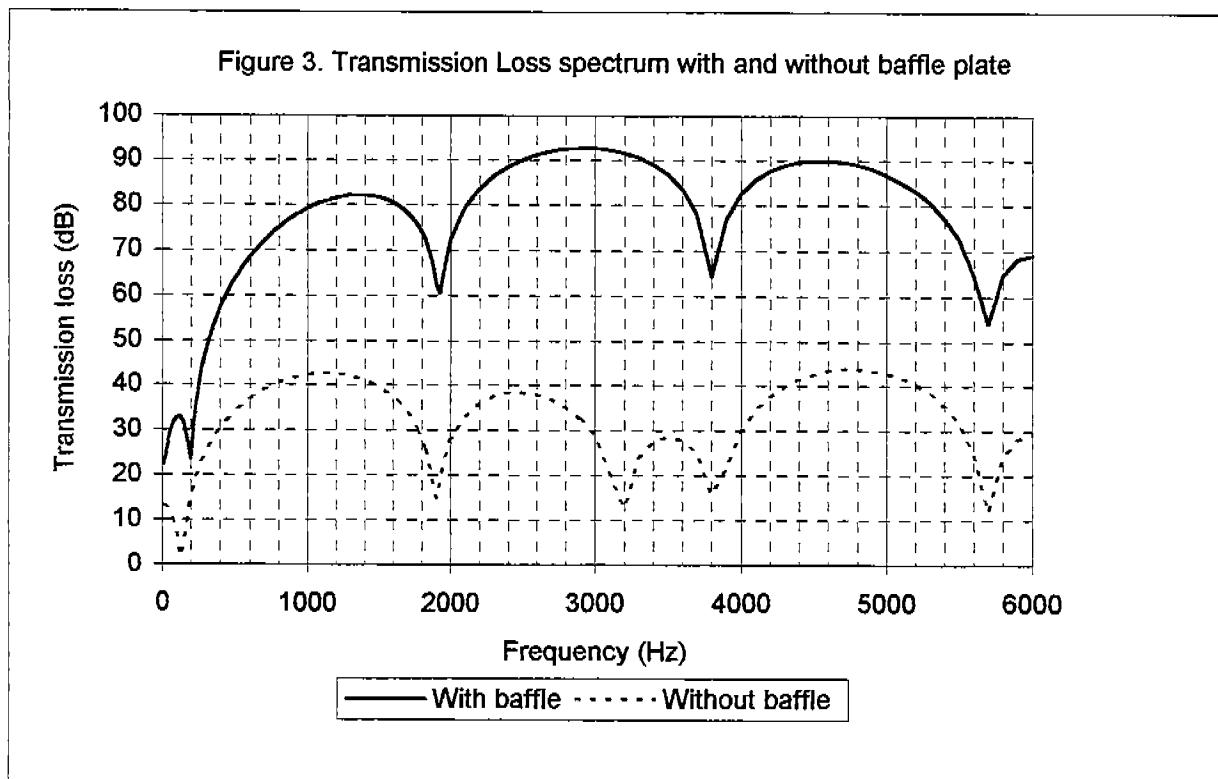


Figure 4. Natural frequencies by TFM and FEM methods

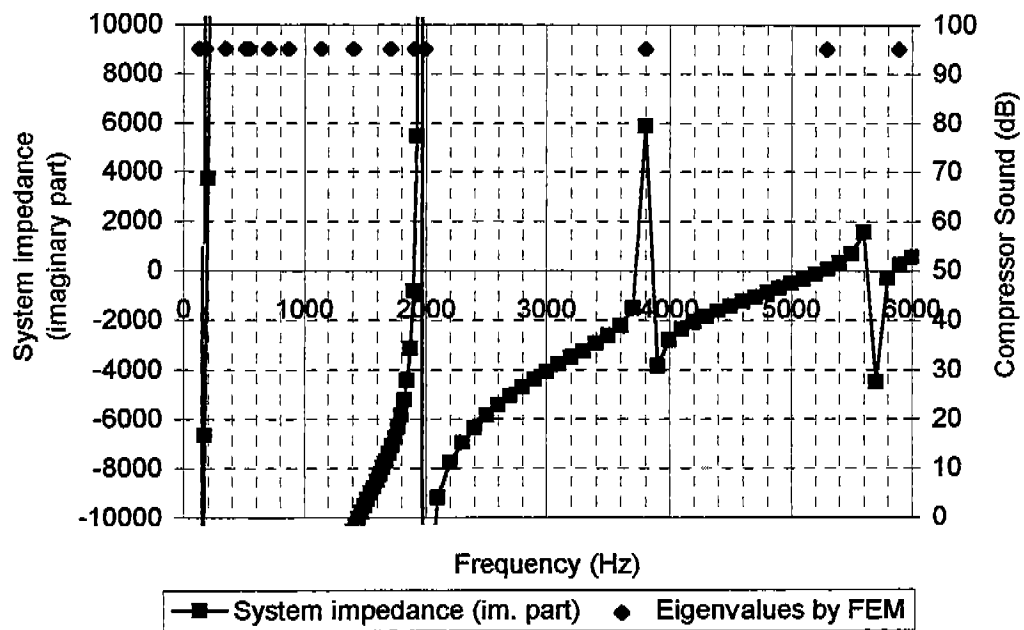


Figure 5. Comparison of spectra of transmission loss by TFM and tested compressor sound pressure

